

# RESULTANT OR BASIC INSULATION – WHICH IS THE BEST PREDICTOR OF CLOTHING PERFORMANCE?

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## INTRODUCTION

Most predictive models or indices accounting for the effects of clothing, assume or predict a value for the actual clothing that is relevant for its actual performance during the given conditions – the resultant value. The interpretation, however, of such predictions are complicated by the fact that most information about clothing performance is based on its basic insulation value ( $I_{cl}$ ) and basic evaporative resistance value ( $R_{e}$ ). Both values are standardized measurements referring to ideal, wind-still, static conditions [9], rather than values representing the ultimate function of the ensemble during realistic conditions (resulting values). Total insulation values ( $I_{Tot}$ ) decrease as a result of the action of wind and body motion on the boundary air layer. However, in addition the pumping action of clothing with body movements and the penetration of wind through porous outer layers, reduce the insulating capacity of clothing itself ( $I_{cl}$ ). Several investigators have reported significant differences between the standard insulation value ( $I_{cl}$  or  $I_{Tot}$ ) and the resulting insulation during realistic conditions [4, 5, 8, 12, 14]. Some investigators have attempted to derive generalized formulas to describe the relationship between standard values and resultant values [4, 5]. Umbach [14] has adopted standardized tests with a moving manikin for his predictive model of clothing performance.

The present paper examines reported differences between standard measurements of clothing insulation and resultant values under wear conditions and the impact of such differences on the accuracy of predictions using heat exchange models.

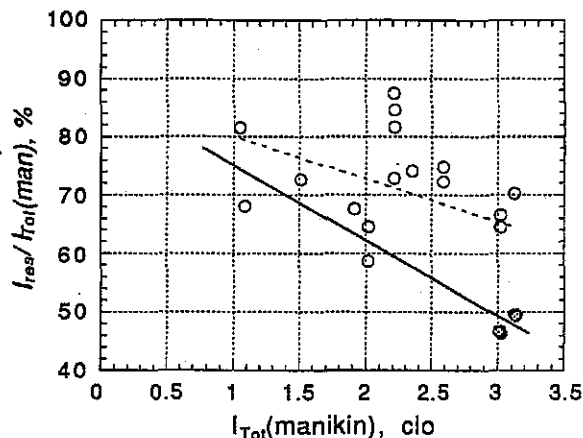
## METHODS AND MATERIALS

Thermal insulation of clothing is measured with a thermal manikin under standardized conditions [9]. The manikin is static and standing in a climatic chamber with negligible air velocity (<0.1 m/s). Under these conditions each garment has a characteristic basic insulation value ( $I_{cl}$ ) and a total insulation value ( $I_{Tot}$ ). Many reports and standards contain tables with standard insulation values for many different types of clothing [9, 10, 11].

This review is based on an analysis of data published in the literature and on data from a series of experiments in our laboratory on human subjects exercising in cold environments wearing different types of cold weather clothing. The experiments comprise many different combinations of activity level, type of activity, clothing insulation level and cold climate.

## RESULTS AND DISCUSSION

In the figure below measured total insulation values are compared with standard manikin values. Clothing has been measured on subjects during walking or bicycling under a variety of climatic conditions in our laboratory [2, 3, 6]. Manikin values have been measured according to ISO [9]. It can be readily seen that the resultant values for  $I_{Tot}$  were always lower than the standard values. Variation in reduction depended on such



factors as intensity of work, amount of sweating, type of clothing etc. Greatest reduction in  $I_{Tot}$  was observed in experiments with significant sweating (filled circles). The detrimental effect of moisture absorption on clothing insulation and body heat loss has been reported by many investigators [1, 7, 13].

Olesen et al. [11] found reductions in  $I_{cl}$  during walking by up to 46%. Havenith et al. [5] derived a set of formulas describing the reduction caused by wind, body movements, and insulation thickness. One of their regression equations is drawn in the figure (solid line). In comparison with our results their formula seem to overestimate the reduction, particularly at high insulation levels. Apparently, there is an effect of insulation thickness. Sweating and moisture absorption by clothing resulted in greater reductions in  $I_{Tot}$  and can explain some of the large variation among data. In fact, the absorption process contributes to the heat transfer, but the magnitude is difficult to measure.

It is evident, that significant errors arise in predictions of thermal responses, when insulation values used in calculations, are assumed equal to resultant values. The higher the activity level, the greater will be the error. Accordingly, in the heat prediction models are likely to overestimate heat stress at moderate temperatures and underestimate at high temperatures. In the cold actual heat losses will be significantly greater, than predicted on the basis of tabulated values for typical cold weather clothing. The obvious lack of sufficient knowledge about the dynamic behaviour of clothing in terms of heat exchange, certainly justifies more research in this field

## CONCLUSIONS

Standard values for clothing thermal properties are in most applications not representative for the actual performance of clothing during given conditions.

In a first approximation standard values should be reduced by 20-40% to compare with resultant values predicted for dynamic, active work.

Predictions of thermal stress based on standard values may severely over- or underestimate dry heat losses.

More research is required to develop a better understanding of clothing thermal function during realistic conditions.

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